

## ontario hydro research division

To Mr. F.J. Kee  
Director of Research

### CHARACTERISTICS OF LOW FREQUENCY ELECTROSTATIC AND ELECTROMAGNETIC FIELDS PRODUCED BY VIDEO DISPLAY TERMINALS

S.M. Harvey

As part of a preliminary study of health hazards from video display terminals, operator exposure to low-frequency electric fields has been measured. Special equipment designed to cover the frequency range from dc to 10 MHz was used. No fields presently thought to be directly related to health effects were found.

#### INTRODUCTION

As part of an interdivisional program designed to ensure hazard-free video display terminal work stations, a preliminary study of the low-frequency (0 to 10 MHz) electrostatic and electromagnetic fields produced by a variety of terminals has been made. The study differs from most studies of this type in that it attempts to measure the actual fields to which an operator would be exposed while seated at the keyboard of the instrument, and in that the frequency coverage extends to dc..

Because this is the first Research report on this topic, a detailed description of the techniques and findings is given. Some of the material has been placed in appendices to avoid an overly long report.

#### BACKGROUND

Since the widespread adoption of the video display terminal (VDT) as a key component of office equipment, there have been

|     |                |      |        |      |                   |            |          |
|-----|----------------|------|--------|------|-------------------|------------|----------|
| job | 740616-424-900 | file | 817.22 | date | December 16, 1982 | report no. | 82-528-K |
|-----|----------------|------|--------|------|-------------------|------------|----------|

numerous reports of physiological effects experienced by the VDT operators. Reported effects have ranged from fatigue to fetal deformity or miscarriage.

Many studies have been made to try to find a mechanism by which the VDT could cause the reported physiological problems, but so far no specific link has been identified. Ergonomic factors continue to be investigated, but chemical agents, ionizing radiation (X-rays), and high-frequency electromagnetic radiation (including microwaves) appear to have been virtually eliminated as causative factors.

In a recent report, Health and Safety Division pointed out that low-frequency electromagnetic fields from the terminals had not been investigated in spite of several studies which suggested a measurable biological effect from low-frequency fields, particularly of the pulsed variety. It was therefore decided to investigate low-frequency fields as part of a larger program aimed at providing hazard-free VDT work stations.

It is important at this point to make a distinction between low-frequency fields and high-frequency fields. High-frequency fields (for lack of a better definition these will be taken to be fields oscillating at more than 10 MHz) are largely radiative, ie there is an outward flow of energy from the source. Health effects are associated with accumulative absorption of this energy by the body tissues. Most occupational health and safety standards are drafted to limit energy absorption to safe levels by restricting either the field levels or the duration of the exposure.

Low-frequency fields are largely non-radiative and are not significantly absorbed by body tissue. No health effects have been proven at the levels normally associated with occupational exposure. However, recent experiments have raised the possibility of an interaction with the nervous system at moderate field strengths. Pulsed fields with a repetition rate between 15 and 30 Hz are presently under suspicion.

Existing standards, even when arbitrarily extended to the low-frequency region, offer no guidelines on the measurement of occupational exposure to these very low-frequency fields. As techniques developed for radiative fields are clearly inappropriate, new methods are needed.

#### BASIS OF THE MEASUREMENT METHOD

The problem in the present study is to measure the low-frequency fields that will exist at a person's body when the person is located close to a small device with both a static and a varying charge distribution.

According to the laws of electrostatics, a field exists between any two surfaces that are at different potentials, the relevant surfaces in the present study being the ventral skin or clothing surface of the operator and any portion of the VDT carrying a static charge. For two infinite conducting plane parallel surfaces, a uniform field exists having a value of 1 V/cm if the surfaces are 1 cm apart with a potential difference of 1 V. For other surfaces, the field will be non-uniform and will depend on the shape, conductivity and extent of the surfaces as well as on their separation and potential difference.

Electrostatics can be applied to slowly varying electric fields over short ranges and remain a good approximation over distances of the order of 1 m for fields varying at a rate of several MHz. Therefore, a measurement system which is based on electrostatics rather than radiation theory should be capable of covering the low-frequency range (less than 10 MHz) electric fields at least for equipment which is close enough to be operated by hand.

It is difficult to measure arbitrary electrostatic fields as these can vary quite rapidly over small distances and are easily perturbed by the measuring equipment. These problems can be removed by measuring the field at the surface of a flat conducting plate which is maintained at a known potential, ie ground potential. At such a surface the field is oriented at right angles to the surface and is relatively uniform, allowing unperturbed measurement.

Under certain conditions, the electrically grounded flat plate will provide a reasonable simulation of the human body. These include:

- similar surface area exposed to the source,
- similar orientation relative to the source,
- moderately conductive and uncharged bodies.

Human bodies may carry an electrical charge, potentials of up to  $\pm 2$  kV relative to ground having been observed. However the charge is likely to be small in the anti-static environment of an "electronic office", and in any event would likely redistribute itself so as to minimize any internal fields. These factors suggest that a properly designed grounded plate may provide a "worst case" measurement of the fields to which an operator would be exposed.

In the present work, a flat metal plate is used to simulate the frontal surface of the VDT operator. There is no doubt that a

better simulation could be used. However the additional complications can not be justified at this stage of the program.

#### MEASURING EQUIPMENT

Most of the measurements in this study were made at the surface of a grounded sheet of copper foil 30 cm (1 ft) wide and 122 cm (4 ft) high located in a vertical position on the floor at a horizontal distance of 30 cm (1 ft) from the centre of the CRT display screen and directly in front of it. The frontal area of the sheet is similar to that of a seated operator and the location represents a "closest approach" position as shown in Figure 1. The field sensor is located on the copper sheet level with the CRT screen.

The field sensor consists of a circular copper plate 11.5 cm in diameter located 1 cm from the copper foil and insulated from it. The plate and 2 m of RG58/U coax form a capacitive divider whose voltage is measured with appropriate equipment. Using available equipment, the system response extends from 0.005 Hz to about 10 MHz in two overlapping ranges and is extended to dc by manually "chopping" the field. Full details of the measurement system and calibration procedures can be found in Appendix A.

For convenience in finding field maxima and minima, a small field probe was also used. The small probe has an 11 cm square ground plane. Therefore the fields at this surface will not be the same as those measured at the surface of the larger sheet and direct quantitative comparisons are not meaningful.

All measurements were made with the VDT unit placed on a wooden table in a low-background basement room.

#### UNITS SELECTED FOR TESTS

Four different terminals of varying vintage from three different manufacturers were selected for detailed study. The oldest, date of manufacture unknown, was purchased by the Research Division in 1979. The newest was manufactured in October 1981 and carries a sticker stating compliance with Part 15 of FCC rules for Class A computing device (these rules limit radiated electromagnetic interference). The two newest units could be set to provide an interlaced picture although interlace was not normally used due to an annoying display flicker. All CRT screens had approximately an 18 x 24 cm display area.

## FIELD CHARACTERISTICS

All four terminals were found to produce qualitatively similar electric fields. The field characteristics are described below with the range of field parameters indicated in each case, and the results are summarized in Table I. A detailed description of the fields from one unit is given in Appendix B.

1. A dc electrostatic field is produced by the positively charged surface of the CRT display screen. The dc field may momentarily exceed 100 V/cm when the terminal is first turned on. After about one half hour of operation the field will lie in the range from 7 V/cm to 70 V/cm depending on the unit tested, an equilibrium value presumably being reached when the charge leakage from the screen just balances the electron beam current. The newest terminals do not necessarily have the lowest fields.

The dc field is strongest directly in front of the CRT display screen and decreases quickly with increasing distance, the approximate relation being  $E \propto R^{-2.5}$ .

2. The dc field is modulated, when a display is present, by the process of writing on the CRT screen. The modulation waveform has a 60 Hz repetition rate and can be quite complex, depending on the display format. For a fixed format, the modulation amplitude increases with the brightness of the display.

A half-screen display produces the maximum modulation amplitude. The maximum modulation amplitude ranges from a high of 1.1 V/cm rms for one of the older units at maximum brightness to about 0.3 V/cm rms for the two newest units. Detectable harmonics extend up to about 1 MHz, although 20 kHz is a more practical measurement limit.

Modulation components below a frequency of 60 Hz are normally absent at the limit of sensitivity, but could be introduced by selecting special displays; for example, interlace (30 Hz), or a blinking cursor on a clear screen (0.5 to 2 Hz). When present, the amplitude of these field components is 10 mV/cm rms or less.

It should be noted that the electrostatic field will also be modulated by the operator's movements, ie while making keyboard entries. However, this effect was not studied.

3. A pulsed field with a repetition rate of about 16 kHz (the line scan frequency) is produced by the high-voltage fly-back circuitry and is present at all times when the unit is

turned on. The pulsed field is strongest at the back or side of the terminal near the flyback transformer and relatively quite weak at the front where it is shielded by the chassis and CRT. The back-of-set fields fall to the same level as experienced by the front-of-set operator at a distance of 120 cm (4 ft) or less.

The zero to peak pulsed field amplitude at the front of the terminal ranges from a high of 1.7 V/cm for one of the older machines to a low of 0.2 V/cm for one of the newer ones. The rise time of the pulse is typically 2 to 4  $\mu$ s. RMS amplitudes of the fundamental are about 10% of the peak pulse amplitude and harmonics can be measured up to 1 MHz.

4. Logic circuits produce variable low-level pulsed fields over a wide frequency range. Component amplitudes are less than 1 mV/cm rms, but can be somewhat higher close to the keyboard. These pulsed fields are largely absent when the terminal is in a "quiescent" state.

TABLE I

SUMMARY OF ELECTRIC FIELDS MEASURED AT A  
GROUNDED CONDUCTING SURFACE 30 cm FROM THE CRT SCREEN UNITS -  
VOLTS PER CENTIMETER (V/cm)

|                                                       | VDT Unit |        |        |        |
|-------------------------------------------------------|----------|--------|--------|--------|
|                                                       | 1        | 2      | 3      | 4      |
| dc fields, about half hour after turn-on              | 60       | 7      | 70     | 60     |
| maximum modulation amplitude, rms (normal brightness) | 0.60     | 0.65   | 0.25   | 0.30   |
| 16 kHz pulse peak amplitude                           | 0.55     | 1.7    | 0.23   | 0.19   |
| approximate rms amplitude                             | 0.1      | 0.3    | 0.05   | 0.03   |
| other fields, rms amplitude                           | <0.001   | <0.001 | <0.001 | <0.001 |

### EFFECT OF ADDED SHIELDING

- (a) In order to test the effect of case shielding the plastic case of the oldest unit was lined with copper foil which was grounded to the VDT chassis via the hold-down screws.

The 16 kHz pulse amplitude from the flyback circuit was reduced by a factor of six in front of the set. At the back of the set the pulse amplitude was reduced by a factor of 20. Other field components were not significantly affected.

- (b) In order to test the effect of transparent conductive CRT screen covers, a grounded open wire mesh was placed in front of the CRT display screen.

The amplitude of the modulated dc field was reduced by a factor of 20. Flyback pulsed fields were reduced slightly at the front of the set, but no change was observed at the back.

### COMPARISON WITH A COLOUR TV RECEIVER

For comparison purposes, electric fields produced by a 20-inch colour TV receiver of recent manufacture were measured. The results were as follows:

- dc fields were very weak, being consistently less than 5 V/cm. This may be a result of the internal mask used in the set tested;
- the 60 Hz repetition rate modulation component was very strong. A person sitting 120 cm (4 ft) from the TV receiver would be exposed to the same modulation amplitude as a person sitting 30 cm (1 ft) from a typical VDT. This strong modulation field should not be surprising in view of the fact that TV pictures are usually much brighter than VDT displays;
- the 16 kHz pulse fields were near the high end of the amplitude range observed from the terminals.

### REMARKS CONCERNING POSSIBLE HEALTH EFFECTS

The measurements made in this study show that no VDT operator will be exposed to low-frequency electric fields in excess of any known occupational health and safety guideline. Persons working within 30 cm (1 ft) of the back of some sets could receive an exposure in excess of the most restrictive standards, but as it is difficult to operate a keyboard from this position, the risk will be largely confined to service personnel.

No evidence for pulsed fields between 15 and 30 Hz was found. A weak, low-frequency component at 30 Hz is produced by interlace but the interlace option, if provided, is seldom used.

DC fields can be of substantial magnitude. Although there are no known direct health effects from such fields, an indirect effect from atmospheric positive ions has been suggested.

#### CONCLUSIONS

Low-frequency electric fields produced by a selection of VDT's have been measured. The measuring equipment has been designed to yield values representing the partial body exposure that would be experienced by an operator seated at the keyboard at a distance of 30 cm (1 ft) from the display screen.

The fields are composed mainly of two components:

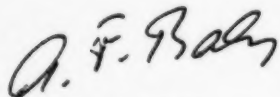
1. A modulated dc field produced by the CRT. During normal operation the dc field may have a magnitude of between 7 and 70 V/cm depending on the make of terminal. The modulation has a distorted 60 Hz waveform and an rms amplitude between 0.25 and 0.60 V/cm.
2. A pulsed field with a pulse repetition rate of approximately 16 kHz. The peak pulse amplitude is between 0.2 and 1.7 V/cm. RMS amplitudes are estimated to be between 0.03 and 0.3 V/cm.

The fields are characteristic of raster-scan CRT devices, including television sets.

In the frequency range from dc to 10 MHz, no fields having characteristics presently known or suspected of being detrimental to human health were found. In the event that health or safety concern are raised, the fields are easily reduced by adding local shielding to the equipment case.

Service personnel may be exposed to fields in excess of some standards at the rear of the set. In this regard, case shielding would be of little benefit as servicing would require removal of the case.

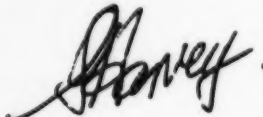
Approved:



A.F. Baljet  
Manager  
Electrical Research Dept

  
SMH:km

Submitted:



S.M. Harvey  
Engineer - Physicist  
Science Section



## APPENDIX A

### FIELD MEASURING EQUIPMENT AND CALIBRATION

#### 1. SENSOR GEOMETRY

The field sensor is designed to provide an output voltage proportional to the electric field normal to the surface of a flat conducting plate at ground potential.

The sensor consists of a 1 mm thick circular copper plate of 11.5 cm diameter mounted parallel to the grounded plate with an air gap of 1 cm. The circular plate is connected to the centre pin of a BNC connector attached to the back side of the grounded plate. A 2 m length of RG58/U coax completes the sensor geometry. The sensor is shown in Figure A1.

#### 2. SENSOR EQUIVALENT CIRCUIT

The sensor equivalent circuit is shown in Figure A2. When connected to a voltage measuring device with input resistance  $R_L$  and input capacitance  $C_L$ , the frequency response is as shown in Figure A3.

#### 3. VOLTAGE MEASURING EQUIPMENT

- (a) For very low frequency analysis, the sensor is connected to a Keithley Instruments Model 610B analog electrometer. According to the instrument manual, the 610B has an input impedance of greater than  $10^{14}$  ohms shunted by 22 pf.

Voltages which do not change within the analog meter time constant can be read directly on this instrument. For faster changes, a low impedance analog output is available for display on an oscilloscope or spectrum analyser. The bandwidth of the output circuitry is several kHz.

- (b) For higher-frequency analysis, the sensor is connected to a Tektronix 465 oscilloscope with a 100 MHz bandwidth and an input impedance of  $10^6$  ohms shunted by 20 pf. From Section 2, it is seen that the sensitivity will be identical, only the low-frequency limit being changed by the lower input resistance. The 465 also has a low impedance analog output which may be connected to a spectrum analyser.

(c) The spectrum analysers used for measuring low-level voltages in the presence of large signals were:

- (i) HP3582A - Frequency Range 0 to 25 kHz  
- Input Impedance 1 M $\Omega$
- (ii) HP8568A - Frequency Range 100 Hz to 1.5 GHz  
- Input Impedance 50  $\Omega$

The dynamic range of these instruments is of the order of 80 dB.

#### 4. SENSOR CALIBRATION

Calibration was performed by exposing the sensor to a known uniform field produced by a 30 cm x 50 cm plate located 10 cm from the grounded plate and directly over the sensor (see Figure A1). The field in V/cm produced by this arrangement is to sufficient accuracy equal to 1/10 of the voltage applied to the calibration plate up to a frequency of above 1 MHz.

A reasonable upper limit for the frequency response of the sensor is the point at which the length of the coax cable is 10% of the signal wavelength. This limit occurs at 10 MHz for a 2 m cable.

The lower frequency limit with the sensor connected to the 610B electrometer was determined by recording the system response to a step-function dc field.

A plot of the calibration data is shown in Figure A4.

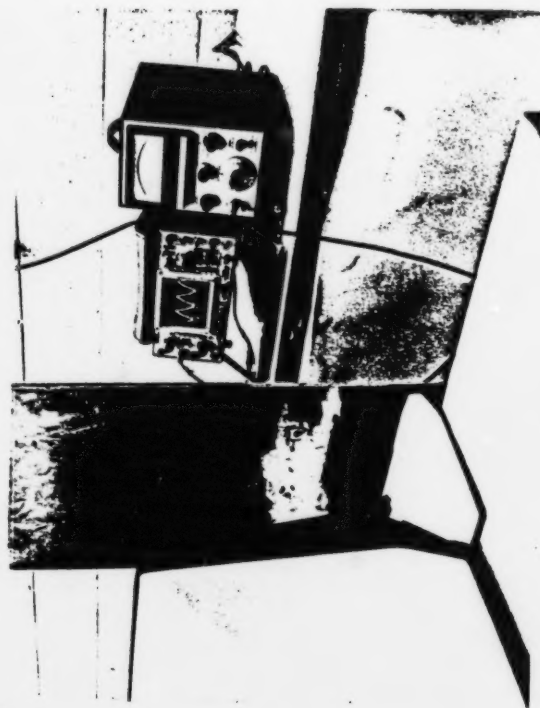
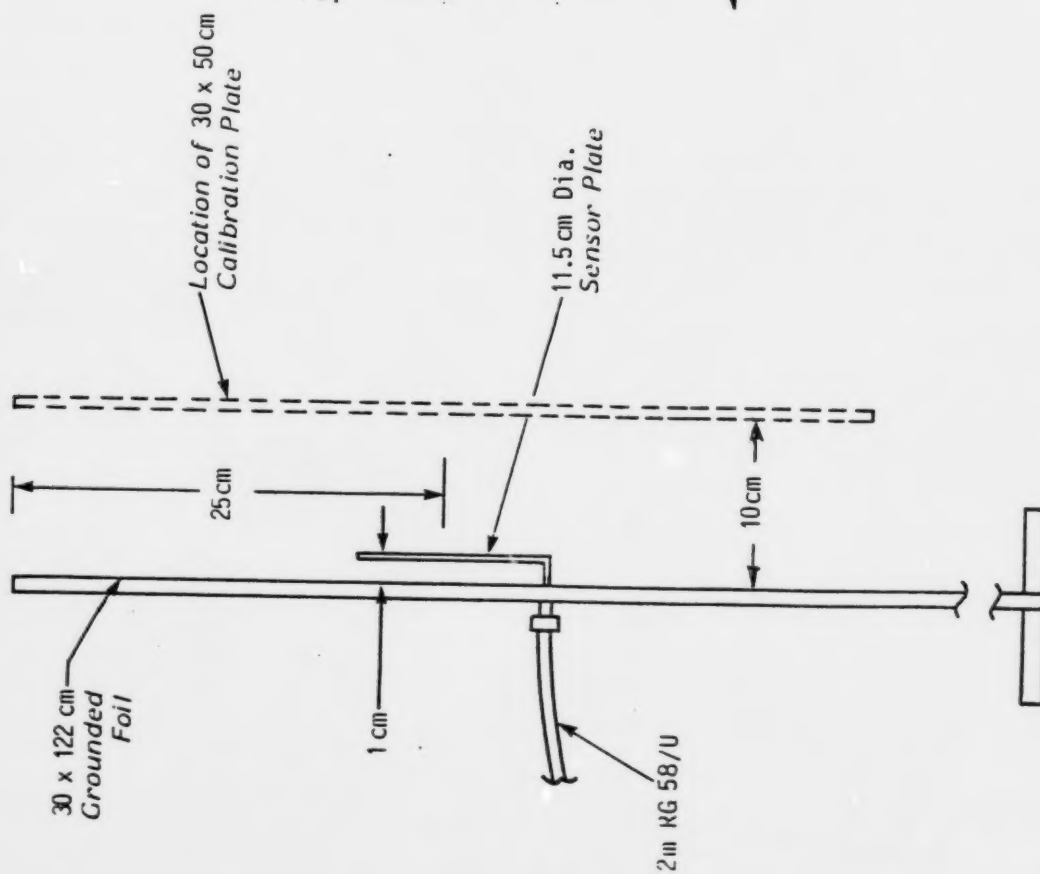


FIGURE A1  
E-FIELD SENSOR CONFIGURATION

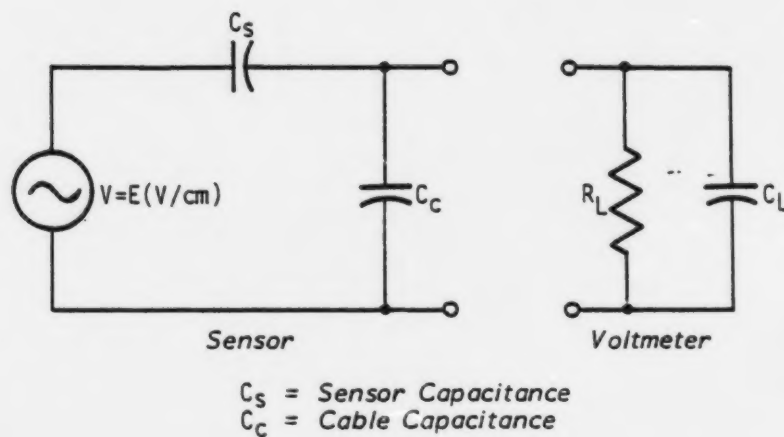


FIGURE A2  
SENSOR EQUIVALENT CIRCUIT

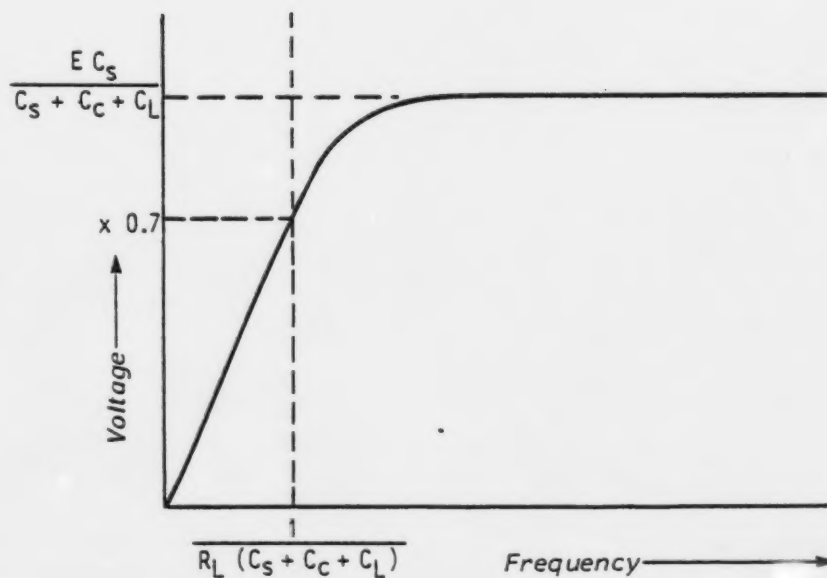


FIGURE A3  
THEORETICAL FREQUENCY RESPONSE

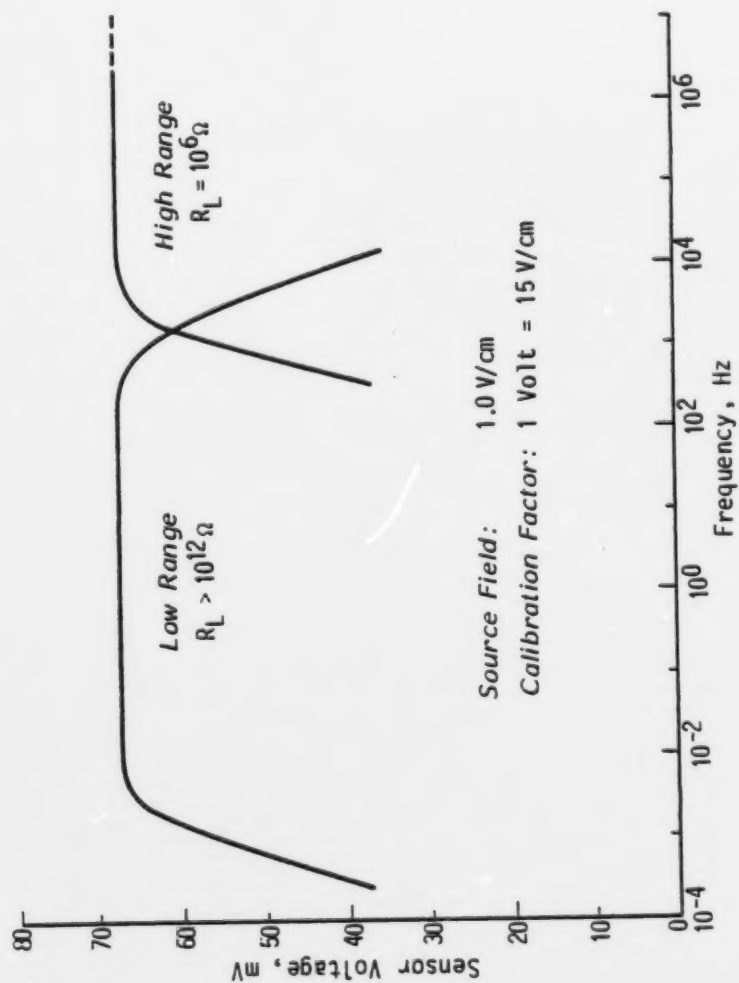


FIGURE A4  
 E-FIELD SENSOR CALIBRATION DATA

## APPENDIX B

### DETAILED STUDY OF LOW-FREQUENCY ELECTRIC FIELDS PRODUCED BY A VIDEO DISPLAY TERMINAL

#### 1. DESCRIPTION OF THE TERMINAL

The terminal selected for a detailed study was an early model of limited intelligence. This model has a detachable keyboard and an 18 cm x 24 cm display area. The brightness control is ganged with the off/on switch instead of being preset internally.

A flashing cursor is set automatically on turn on and the unit can be set to write and scroll automatically by taping down one key.

A full display consists of 24 lines of 80 characters each. A full scan consists of 265 lines, 10 lines being used for each line of text, according to a visual count of the repetition rates. The refresh rate is 60 Hz and there appears to be no interlace.

#### 2. METHOD OF MEASUREMENT

For field measurements, the VDT was placed on a wooden table near the centre of a basement room with a low background level of extraneous fields.

The grounded reference plane was located vertically at a horizontal distance of 30 cm (1 ft) from the centre of the CRT screen, such that the field sensor was at the same level as the screen. Previous measurements had shown the CRT generated fields were maximum in the front horizontal plane or slightly above it.

For angular measurements of the pulsed flyback fields, the terminal was mounted so that it could be rotated about a vertical axis through the centre of the unit.

DC fields (ie, those fields which changed slowly in comparison with the time constant of the system) were measured by chopping the field with a grounded metal plate. This could be done quite conveniently by hand.

The results, described below, are divided into the following three categories according to the method of measurement: dc fields, ac fields measured on the low-frequency range, and ac fields measured on the high-frequency range.

### 3. RESULTS

#### 3.1 DC Fields

DC fields depended on the previous operating history of the unit and could be changed, ie by touching the CRT screen to bleed off charge. Therefore, a standardized procedure was adopted. First, the terminal was allowed to run for an extended period of time. Then it was turned off and the field was measured for 30 minutes. The residual charge was removed as well as possible by touching the screen and the terminal was then turned on again with a display on the screen. Following this the field was recorded for another 30 minutes.

The results of these measurements are shown in Figure B1.

#### 3.2 AC FIELDS BELOW 2 kHz

AC fields with frequencies below 2 kHz were measured with the 610B electrometer in circuit. After some experimentation it was found that these fields consist almost entirely of dc field modulation components whose amplitudes are directly related to the brightness of the CRT display.

##### 3.2.1 Real Time Displays

Figure B2 shows three photographs of low-frequency field waveforms. Picture (a) shows the modulation produced by a blinking cursor on a clear screen against a background of 60 Hz fields from the external environment. The rms field modulation amplitude is about 10 mV/cm. Pictures (b) and (c) show the complex 60 Hz waveform produced by half-screen and full-screen displays. Each of the small oscillations represents the scanning of one line of text.

The peak-to-peak amplitude in Picture (b) is the largest observed for this terminal. It represents a peak-to-peak modulation of 3.2 V/cm or an rms field amplitude of 1.1 V/cm. At normal brightness, the field is about 50% smaller.

##### 3.2.2 Spectrum Analyser Displays

Figures B3, B4 and B5 show HP3582A spectrum analyser displays of the real-time signals with frequency ranges of 0-25 Hz, 0-100 Hz and 0-2.5 kHz respectively. In addition to confirming the real time data, these pictures show the harmonic content of the field modulation.

Notes: (i) Because the brightness control is ganged to the off/on switch, it can not be assumed that all records were obtained at the same brightness.

- (ii) Great care must be taken while recording the lowest frequencies that spurious modulation is not produced by people walking near the terminal.

### 3.3 AC Fields Above 2 kHz

AC fields above 2 kHz were measured with the 465 oscilloscope in circuit. These fields were found to consist almost exclusively of higher harmonics of the dc modulation field and a pulsed field with a repetition rate of 15.9 kHz which originated with the high-voltage flyback circuitry.

#### 3.3.1 Real Time Displays

Figure B6 shows the waveform of the pulsed field. The zero to peak amplitude of the pulsed field is independent of the CRT display parameters, but varies greatly with the sensor location. Figure B7 shows a polar plot of the zero to peak field amplitude obtained by rotating the VDT around a vertical axis. This rotation takes the sensor quite close to the case and a more realistic representation, the locus of constant field, is shown in Figure B8.

The pulsed field is strongest near the corner of the chassis containing the flyback transformer. It is shielded at the front and under the table by the chassis and CRT. Therefore, a person sitting 120 cm (4 ft) from the rear corner will experience the same field amplitude as a person sitting 30 cm (1 ft) from the front of the CRT.

In order to test the effect of internal shielding, the inside of the plastic VDT case (top, back and sides) was lined with copper foil which was grounded to the chassis via the case hold-down screws. A polar plot of the field strength from the shielded terminal is also shown in Figure B7. The shielding had little effect on fields from other sources.

#### 3.3.2 Spectrum Analyser Displays

In order to reduce the amplitude of the pulsed fields and therefore prevent overloading of the spectrum analyser while looking for weak fields all spectral measurements were made with the case shielding in place.

Figures B9 and B10 show spectrum analyser displays for the frequency ranges 0-25 kHz and 0-100 kHz respectively. Figure B11 shows displays for the ranges 0-1 MHz and 0-10 MHz.

Figures B9 to B11 illustrate the following features of the VDT fields:

- (a) A virtually clean pulse spectrum under clear screen conditions.
- (b) The rapid fall-off of dc field modulation harmonics with increasing frequency.
- (c) The absence of significant field components in the 1-10 MHz range.
- (d) The presence of low-level broadband pulsed fields in the automatic writing mode, and some low-level cw fields, ie at 21.5 kHz and 88 kHz.

Some of the higher frequency components were examined at maximum resolution (10 Hz) in a search for sidebands produced by modulation in the range below 60 Hz. No such sidebands were found.

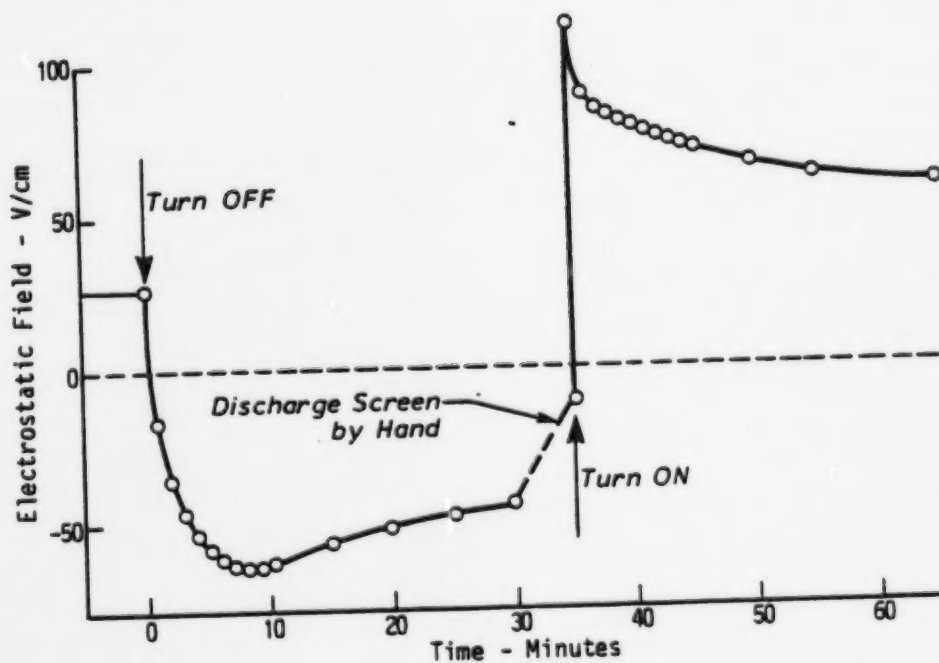
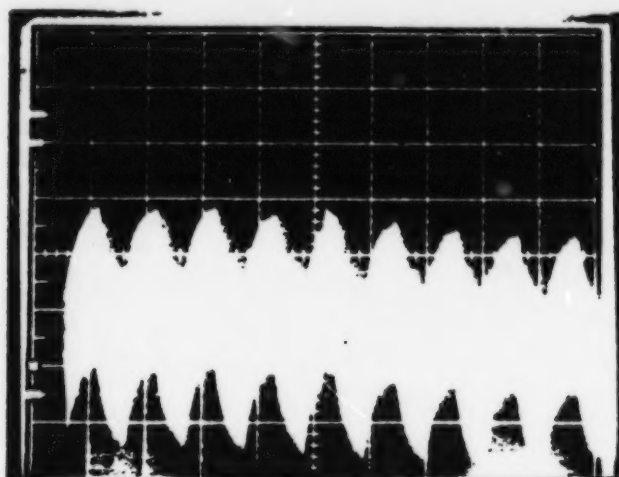


FIGURE B1  
VDT ELECTROSTATIC FIELD



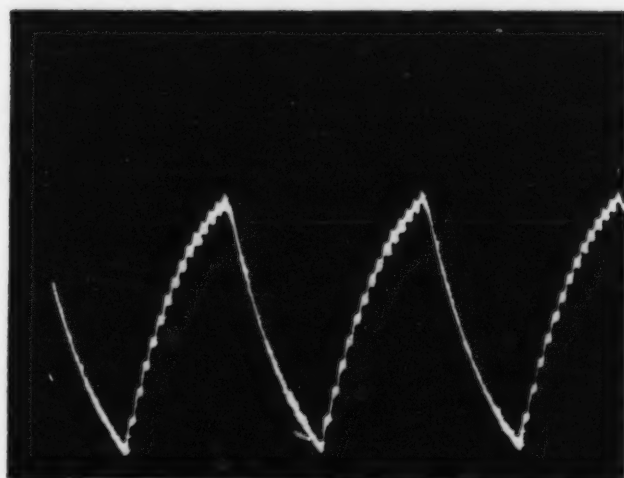
**a) BLINKING CURSOR ON A CLEAR SCREEN**

*Normal Brightness.*

*The trace is broadened by 60Hz background fields.*

*Vertical Scale: 0.03V/cm/div.*

*Horizontal Scale: 0.5 s/div.*



**b) HALF-SCREEN DISPLAY (FIRST 14 LINES OF TEXT)**

*Near Maximum Brightness.*

*Vertical Scale: 0.75 V/cm/div.*

*Horizontal Scale: 5 ms/div.*



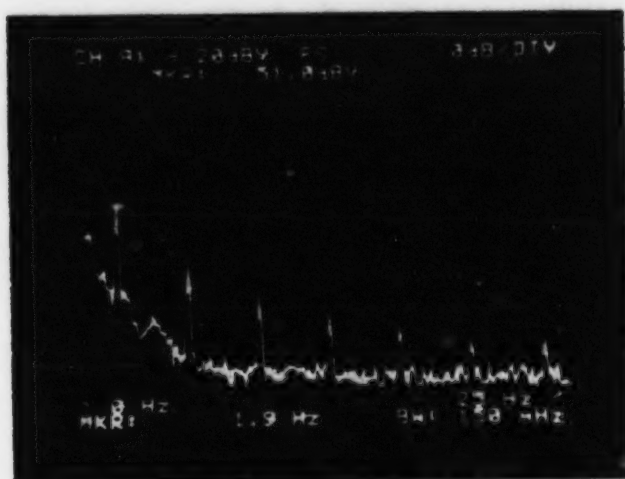
**c) FULL SCREEN DISPLAY (24 LINES OF TEXT)**

*Near Maximum Brightness.*

*Vertical Scale: 0.3 V/cm/div*

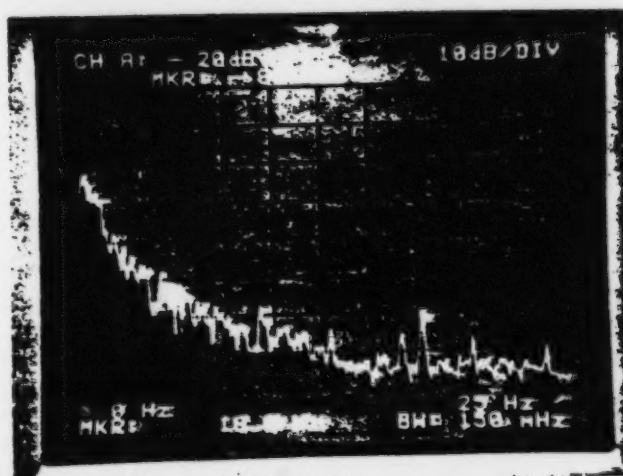
*Horizontal Scale: 5 ms/div.*

**FIGURE B2**  
**LOW FREQUENCY FIELD MODULATION WAVEFORMS**



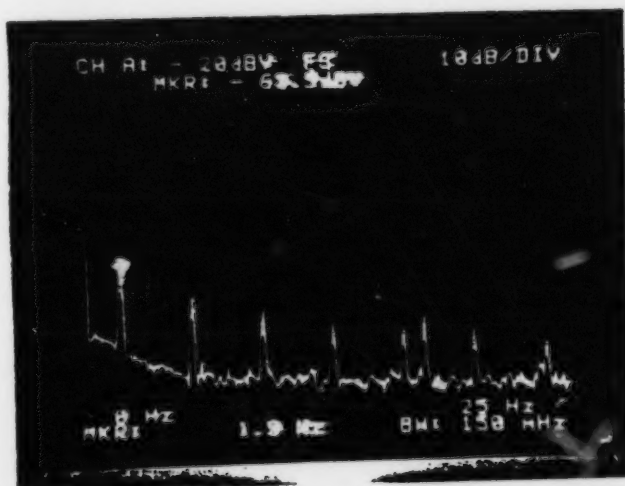
**a) BLINKING CURSOR ON A CLEAR SCREEN**

*The signal has 10dB of pre-amplification. Therefore, the peak at 1.9Hz is -16dBV or 13mv/cm including background.*



**b) CHARACTER KEY DEPRESSED. VDT IS WRITING AND SCROLLING AT 18 CHARACTERS/SEC.**

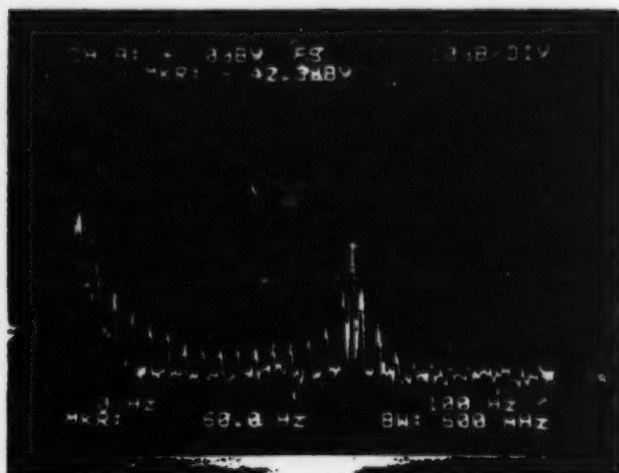
*The signal has 10dB of pre-amplification, putting the 18Hz component at -90dBV or 0.5mV/cm rms.*



**c) BLINKING CURSOR ON A FULL SCREEN**

*The signal has 10dB of pre-amplification, putting the 1.9Hz component at -74dBV or 3mv/cm rms.*

**FIGURE B3**  
**SPECTRUM ANALYZER DISPLAYS, 0-25Hz**



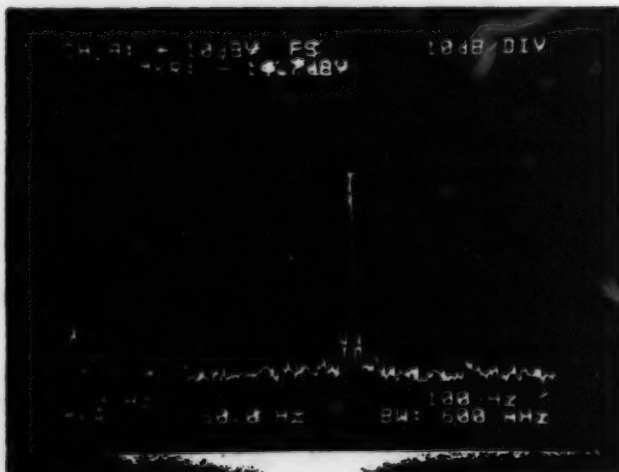
**a) BLINKING CURSOR ON A CLEAR SCREEN**

*Preamplification is 20dB. The 60Hz component is largely due to stray fields from external sources.*



**b) BLINKING CURSOR ON A HALF-FULL SCREEN**

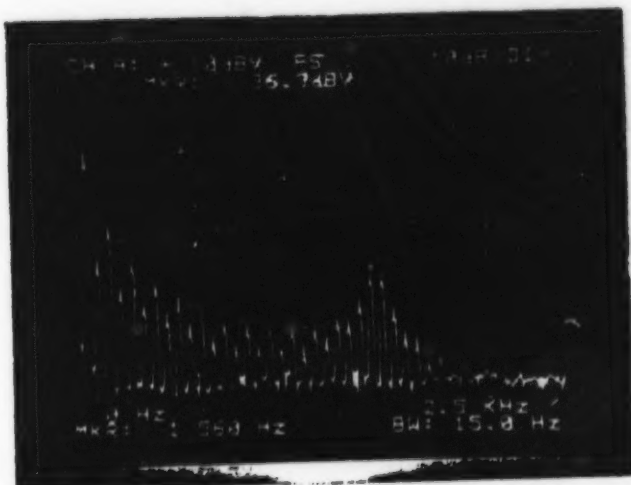
*Preamplification is 20dB. The 60Hz component is -23.8dBV or 1.0V/cm rms.*



**c) BLINKING CURSOR ON A FULL SCREEN**

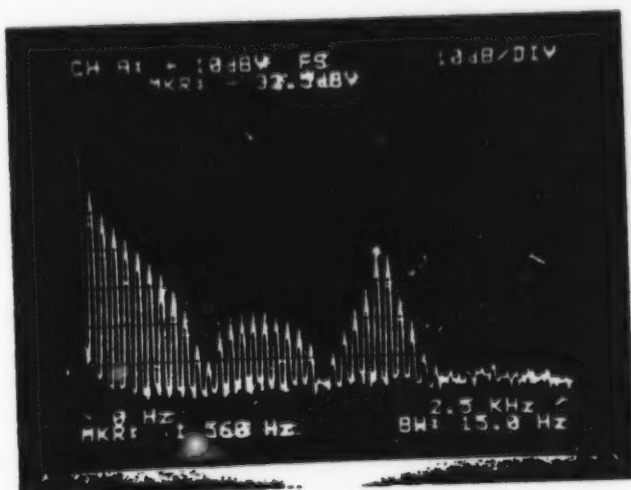
*Preamplification is 20dB. The 60Hz component is -34.7dBV or 0.3V/cm rms.*

**FIGURE B4**  
**SPECTRUM ANALYZER DISPLAYS 0-100Hz**



**a) SCREEN HALF FULL**

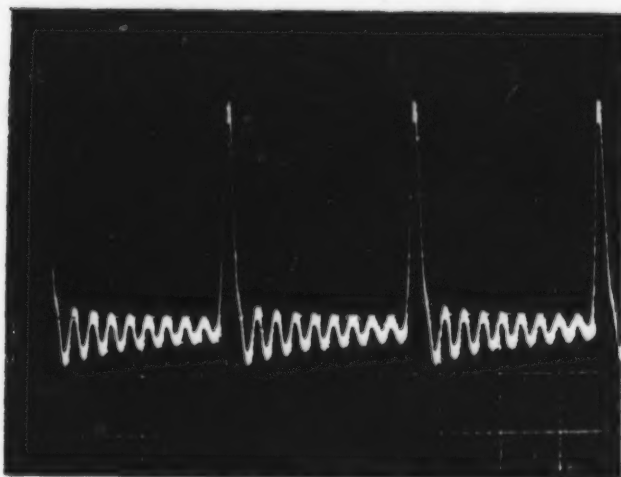
*Preamplification is 20dB.  
The subsidiary harmonic  
maximum at 1.59 kHz  
corresponds to the rate at  
which the lines of text are  
scanned.*



**b) SCREEN FULL**

*Preamplification is 20dB.  
This photo shows the  
dependence of the field  
modulation harmonic content  
on the display format.*

**FIGURE B5**  
**SPECTRUM ANALYZER DISPLAYS 0-2.5 kHz**



Horizontal Scale is  $20\mu\text{s}/\text{div.}$

FIGURE B6  
WAVEFORM OF 15.9 kHz PULSED FIELD

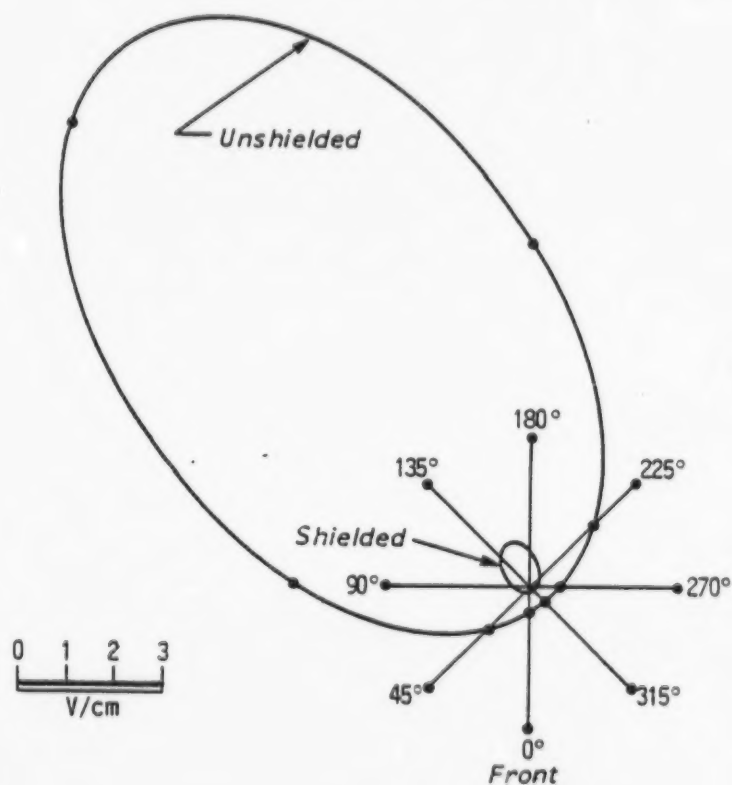


FIGURE B7  
POLAR DIAGRAM OF PULSED PEAK FIELD STRENGTHS  
IN HORIZONTAL PLANE

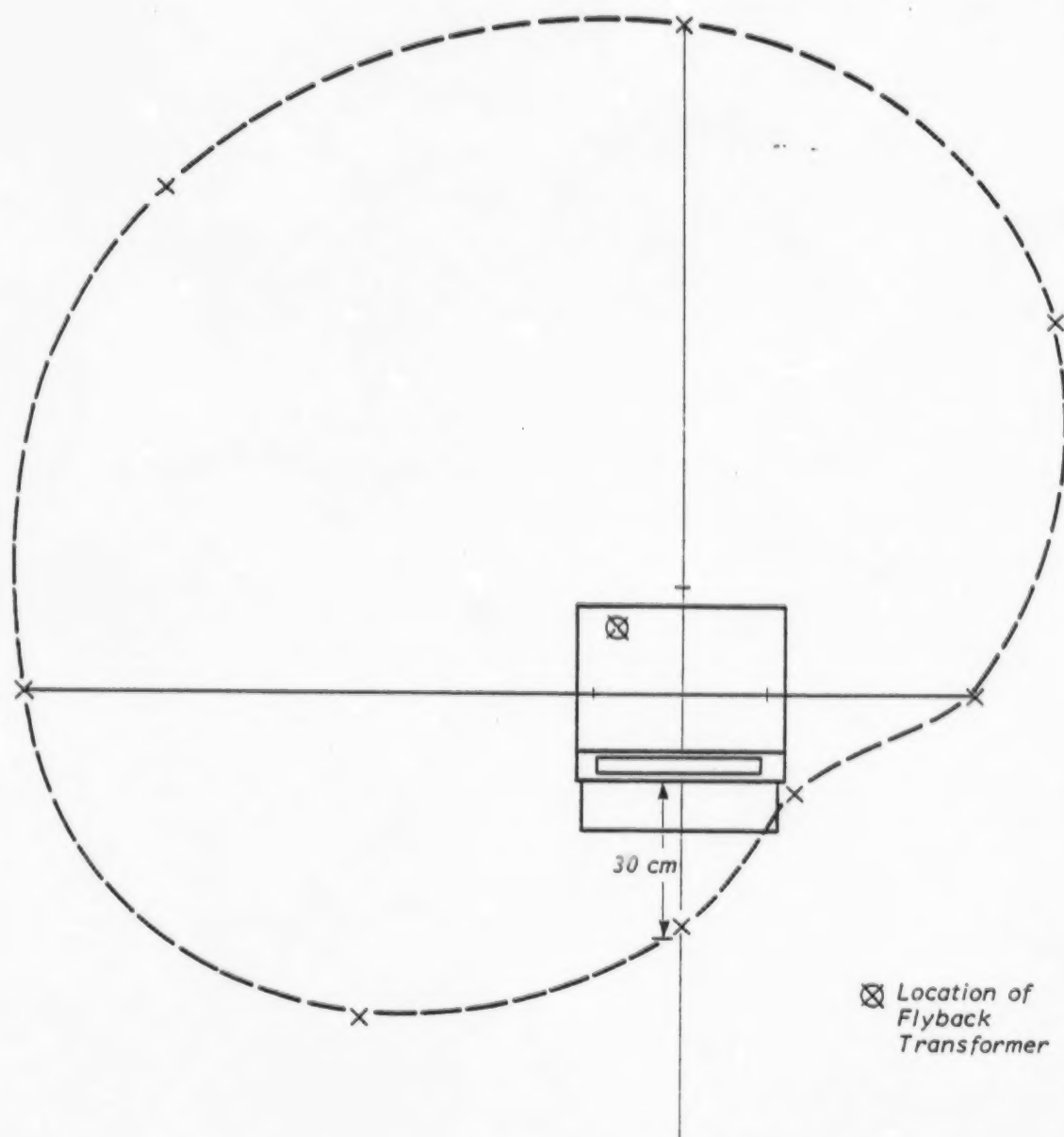
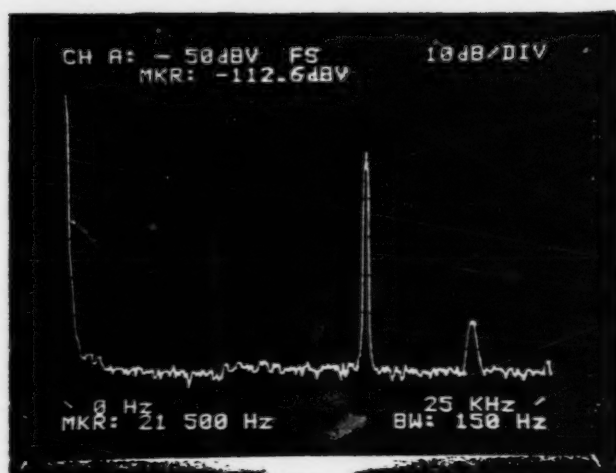


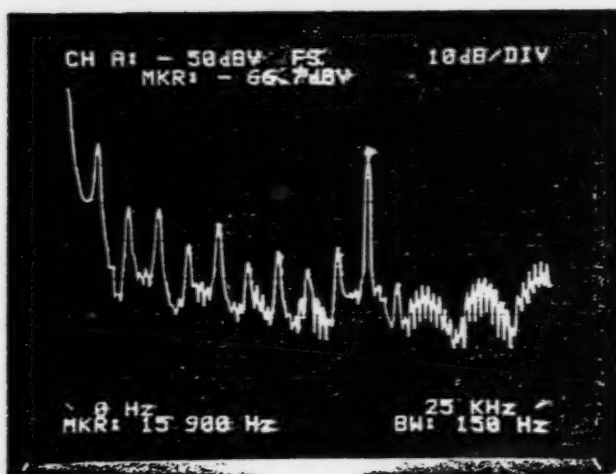
FIGURE B8  
LOCUS OF CONSTANT PULSED FIELD  
(0.55 V/cm PEAK TO PEAK)

160083-RD



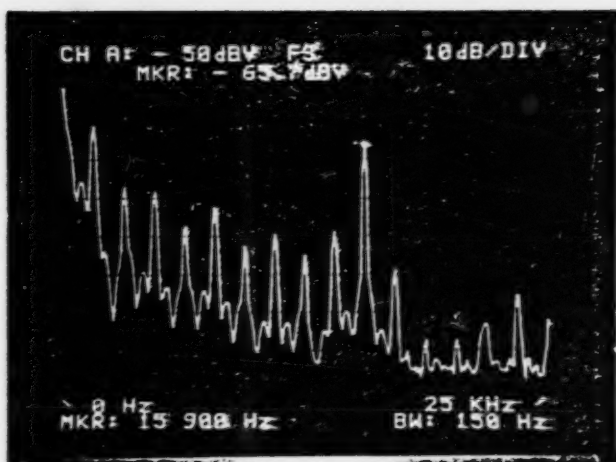
a) BLINKING CURSOR ON A CLEAR SCREEN

Preamplification is 0dB. The 15.9kHz fundamental of the pulse field is shown. The 21.5kHz component is in the  $\mu\text{V}/\text{cm}$  range.



b) HALF-SCREEN DISPLAY, KEY DEPRESSED

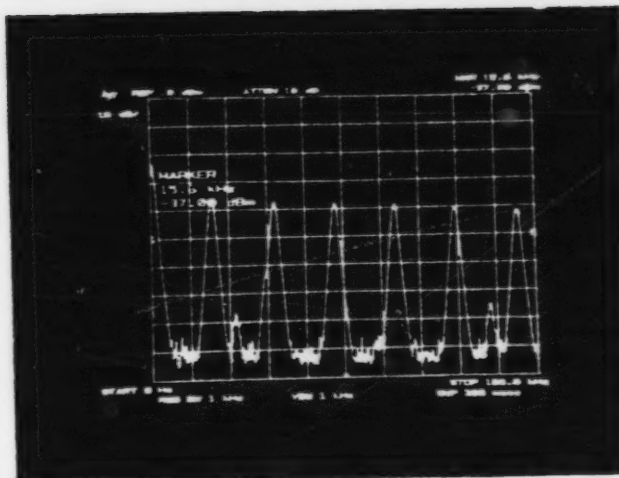
Preamplification is 0 dB. The fine structure disappears when the key is lifted.



c) FULL SCREEN DISPLAY

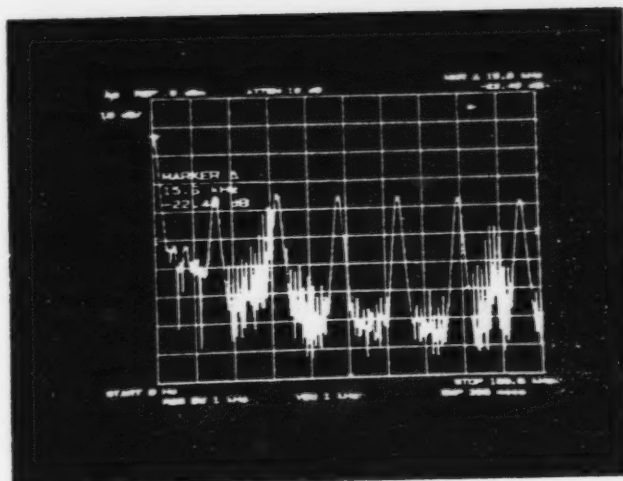
Preamplification is 0 dB. The 60Hz harmonics of the dc field modulation are not resolved in this picture, only the "envelope" is shown.

FIGURE B9  
SPECTRUM ANALYZER DISPLAYS 0-25kHz



a) BLINKING CURSOR ON A CLEAR SCREEN

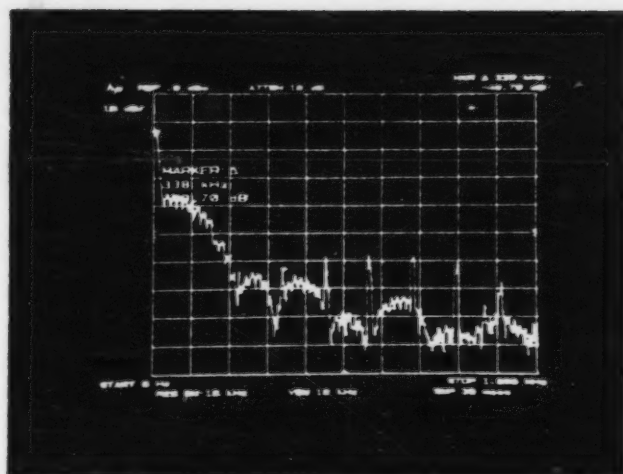
*Preamplification is 16dB.  
Harmonics of the 16kHz pulsed field are shown. The fundamental is -66dBV or 7.5mV/cm rms.*



b) HALF-SCREEN DISPLAY, KEY DEPRESSED

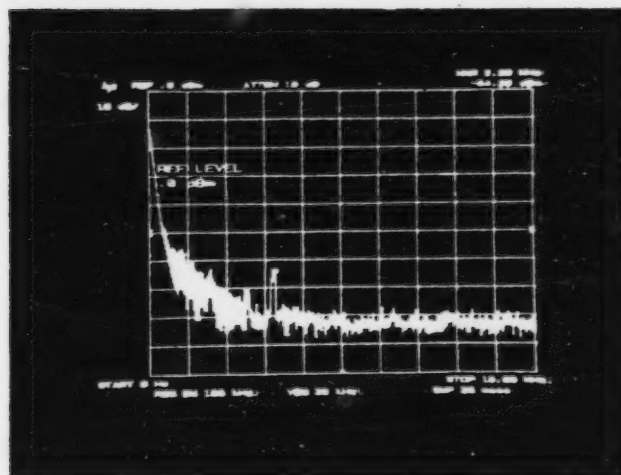
*Preamplification is 16dB.  
The fine structure is not stationary and disappears when the key is lifted.*

FIGURE B10  
SPECTRUM ANALYZER DISPLAYS 0-100kHz



a) HALF-SCREEN DISPLAY WITH KEY DEPRESSED. 0-1MHz

*Preamplification is 16dB.  
The high-frequency peaks  
are not stationary. Their  
amplitude is in the  $\mu\text{V/cm}$  range.*



b) HALF-SCREEN DISPLAY 0-10MHz

*Preamplification is 16dB.  
Small peaks, such as the  
one shown here at 3.2 MHz  
are display dependent.*

FIGURE B11  
SPECTRUM ANALYZER DISPLAYS  
0-1MHz AND 0-10MHz

**POOR**

**QUALITY**

**ORIGINAL**